5-2001

Observations of Currents on the West Florida Shelf Break

Steven D. Meyers
University of South Florida, smeyers@usf.edu

Eric M. Siegel
University of South Florida

Robert H. Weisberg
University of South Florida, weisberg@marine.usf.edu

GEOPHYSICAL RESEARCH LETTERS, VOL. 28, NO. 10, PAGES 2037-2040, MAY 15, 2001

Observations of currents on the West Florida Shelf break

Steven D. Meyers, Eric M. Siegel,[1] and Robert H. Weisberg

College of Marine Science, University of South Florida, St. Petersburg, FL

Abstract. Year-long measurements by five acoustic Doppler current profilers moored across the central West Florida Shelf (WFS) and shelf break reveal new information on the local velocity structure and its temporal evolution. The moorings were between the 30 and 300 m isobaths. At depths greater than about 100 m the currents were sometimes directly affected by the deep ocean. During the measurement period the Loop Current (LC) directly impacted the central WFS three times, amounting to a total of about 13% of the year. For the remainder of the year the shelf break currents had equal likelihood of flowing northward or southward. Northward currents achieved over 70 cm/s and the southward currents (driven by the LC) achieved 120 cm/s. Neighboring instruments recorded strong (~30 cm/s) currents flowing in opposite directions. Current reversals, in one case totally nearly 100 cm/s within a few days, were also found.

Background

The WFS is a gently sloping region about 200 km wide. From the shelf break, beginning near the 200 m isobath, the continental slope plummets to over 3000 m depth within 50–100 km. Previous published observations of the sub-tidal circulation on or near the central WFS break were typically of limited duration or at a single location [*Molinari and Mayer*, 1982; *Paluszkiewicz et al.*, 1983]. An exception is a study over several months at five stations on the 100–200 m isobaths by *Niiler* [1976]. Emergent from these and other studies is a description of the shelf circulation suggesting that it is generally weak (<30 cm/s), and usually contains a southward component. Additionally, there is little zonal variation, except near the shelf break where seasonal interaction with the Loop Current (LC) occurs. The observations discussed here show a more complex structure.

Several new features of the circulation are presented. Among these are strong along-shelf counter-flowing currents and rapid current reversals. Additionally, the flow is not consistently, or even primarily, southward. Northward circulation is recorded nearly 40% of the time at the shelf break, and a direct influence by the LC at the shelf occurred ≤13% of the time.

Data

An array of moorings, each containing an acoustic Doppler current profiler (ADCP), was deployed on the WFS from January 27, 1995 to February 1, 1996 [*Weisberg et al.*, 1997]. The array roughly paralleled the local isobath gradient between 27.27° N, 84.86° W to 27.81° N, 83.42° W with five moorings between the 296 m and 30 m isobaths (Fig. 1). The three moorings in relatively deep water are examined: TS61, TS51, and TS41, nominally located on the 296 m, 142 m, and 63 m isobaths, respectively. After editing and resampling, hourly velocity vectors are available in 5 m bins at depths of 30–200 m, 20–120 m, and 10–45 m at the respective moorings. To remove tidal and inertial oscillations the data are lowpass filtered, only retaining timescales greater than 36 h. A more complete analysis is given by *Siegel* [1999].

TOPEX-Poseidon (TP) tracks over the Gulf of Mexico (Fig. 1) provide sea level measurements every 10 days. These altimetry data are pre-processed to remove ocean, earth, and polar tides, as well as the mean sea level. The latter removes the ability to compute the mean geostrophic velocity. Note that TP track 91 passes over TS61, allowing for a direct comparison between the in-situ currents and those estimated from TP. Track 167 passes over the southern WFS at an angle nearly perpendicular to the local isobaths, permitting the direct estimation of the local alongshelf geostrophic current anomalies. These altimetric data are examined during the coincident time of the ADCP records. The TP dynamic heights are smoothed along track with a binomial filter created by five applications of a forward and a backward 1-2-1 Hanning filter, the sum of which has a half-power point near 105 km. This is done to eliminate the small scale variability in the measurements that may impact the velocity calculations below. The estimated geostrophic velocity anomalies are essentially unchanged if the number of filter applications varies from 4–10.

Analysis

The ADCP records show significant sub-tidal variations between moorings on the shelf and shelf break. Strong counter-flowing currents are found among TS61, TS51, and TS41. For example, during August 1995 the velocity at TS61 is ~35 cm/s in the upshelf (roughly northward) direction, following a sudden reversal of the circulation, while at TS51, only 37 km away, the flow is 20 cm/s downshelf. These opposing flows persist for almost one month (Fig. 2). In October 1995 there is nearly zero circulation at TS61 but 30 cm/s currents are found at TS51. Counter-flowing currents occur more frequently between TS51 and TS41, such as in April/May 1995, and September/October 1995. The latter includes a near–simultaneous reversal of currents at TS51 and TS41 from one counter state to another. The mechanism behind these counter-flowing currents remains unclear. They are not explained by local wind stress which varies smoothly across the WFS [*Cragg et al.*, 1993].

[1]Washington Department of Ecology, Olympia, WA

Paper number 2000GL012249.
0094-8276/01/2000GL012249$05.00

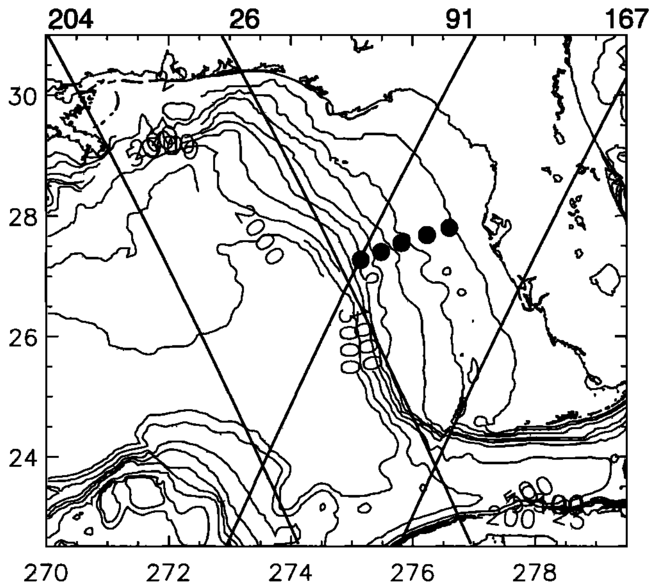

Figure 1. The WFS and its bathymetry. The locations of the ADCP moorings TS61, TS51, TS41, TS21, and TS11, from left to right indicated by the black circles. The TOPEX tracks are indicated.

At TS61 the currents vary from a nearly depth-independent, barotropic state to a strongly baroclinic state with large variations in the vertical. Strong currents (>50 cm/s) are found during April, May, July, and September 1995, and in January 1996, with maximum recorded speeds of over 120 cm/s in early 1996 (Fig. 2). The directions of these large current events roughly align with the isobaths and their durations are from a few days to a few weeks. All of these events contain significant baroclinic structure as inferred from the strong vertical velocity shear, with the maximum current speeds occuring in the uppermost measurement bins. A strong northward circulation occurs during August/September 1995, with maximum speeds of nearly 70 cm/s. Circulation in this direction occurs nearly 40% of the time during the measurement period, but is more typically ≤30 cm/s (Fig. 3a). Neither the strong northward nor southward currents at the shelf break coincide with wind events and so they appear to be of oceanic origin. This is in contrast to the inner-shelf region where the currents are largely wind-forced [*Weisberg et al.*, 2000].

The direction, speed, and vertical structure of the southward events are consistent with the structure of the LC. Composite AVHRR sea surface temperature images (not shown) confirm that the LC impinges on the WFS near TS61 during April/May 1995 and January 1996, whereas the LC is farther away from the shelf during times of relatively weak currents (e.g., March 1995). Imaging from AVHRR cannot confirm the position of the LC during the summer months since the summer mixed layer produces nearly uniform surface temperature across the Gulf of Mexico [*Siegel*, 1999]. The circulation at TS51 is similar to that found at TS61, though somewhat reduced in magnitude or shifted in time. The velocities at TS41 generally do not match those at the two outer moorings (Fig. 2). Thus, the LC does not appear to affect the WFS in unison, particularly for depths shallower than around the 100 m isobath.

Unlike the qualitative measure by AVHRR, altimetry offers a quantitative means for estimating ocean currents via the geostrophic approximation. The TP track 91 contains several positive sea level anomalies with negatives slopes on their eastern sides extending from the deep water to the shelf break (Fig. 4). These features occur during April/May, and July 1995, and January 1996, coincident with the indications of LC intrusions detected by the AVHRR images and the ADCPs. The horizontal extent, magnitude, and orientation of these features are also consistent with the presence of the LC. Additionally, the July 1995 sea level anomaly recorded by TP is similar in magnitude and horizontal scale

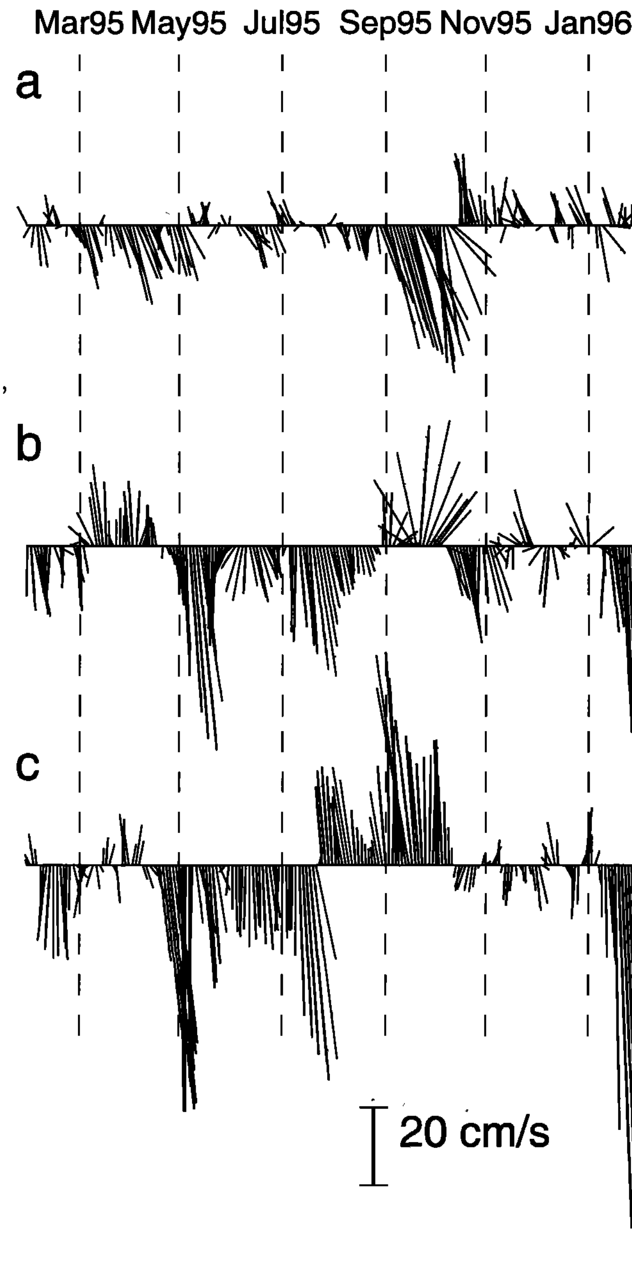

Figure 2. Velocity vector timeseries at 30 m depth at a) TS41, b) TS51, and c) TS61. A 20 cm/s scale is given below c). The vector are plotted every two days after an additional 4-day boxcar filter was applied to the hourly data.

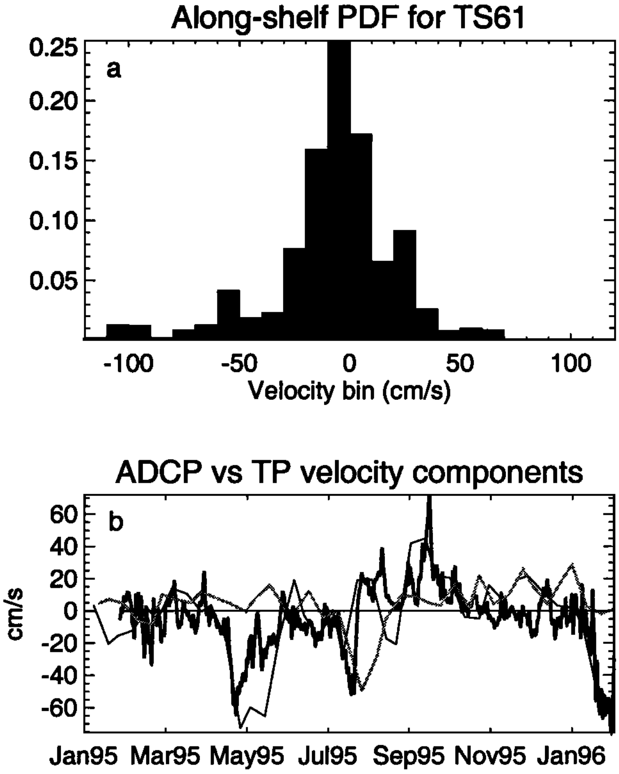

Figure 3. a) The relative occurrence of the along-shelf velocity component in 10 cm/s bins from TS61. b) Velocities near the 300-m isobath of the WFS: the geostrophic velocity $u_\perp$ from TP track 91 nearest TS61 (thin line), the geostrophic velocity $u_\perp$ from TP Track 167, and ADCP velocity component perpendicular to TP 91 from TS61 (heavy line).

to the other anomalies that are confirmed LC intrusions, indicating that this event is also a LC intrusion. The LC impacts on the WFS are brief and intermittent, as shown by both the altimetric measurements and ADCP. The total fraction of time the LC resides on the WFS break during the measurement period is only 13%, as indicated by the fraction of velocity measurements $\geq$30 cm/s (Fig. 3a).

While altimetry does not suffer the seasonal limitations of infrared imaging, it does suffer from a lack of spatial resolution as well as from not being a direct measure of the ocean circulation. It remains to verify the accuracy of the TP-derived currents, particularly in the shallow areas of the WFS. The geostrophic current anomaly can be estimated from the TP dynamic height anomaly as

$$u_\perp = \frac{g}{f}\frac{\partial h}{\partial \eta} \quad (1)$$

where $u_\perp$ is the velocity perpendicular to the altimetric track, g is the acceleration of gravity (980 cm/s^2), f is the local Coriolis parameter, h is the TP height anomaly, and η represents the along-path direction.

The estimated $u_\perp$ generally matches the ADCP measurements (Fig. 3b). The ADCP velocity component parallel to $u_\perp$ from the 30 m bin of TS61 has a linear correlation coefficient with $u_\perp$ of $r = 0.76$. Thus, TP yields a reasonable estimate of the geostrophic velocity anomaly and is a valid tool for locating the LC. The largest absolute difference between $u_\perp$ and the ADCP data occurs during May 1995 and lasts for roughly 1 month. During this time $u_\perp$ overestimates the current speed by 40–50 cm/s. This suggests there may be an ageostrophic component to the circulation at the WFS break.

Discussion and summary

Hetland et al. [1999, 2001] suggested that LC impacts on the southernmost extent of the WFS during the "young" phase of the LC eddy-shedding cycle generates a roughly 10 cm/s trans-shelf southward current along the entire WFS and a northward current of similar magnitude seaward of the shelf break. Only one such impact is detected during the measurement period. Dynamic height anomalies along TP track 167 (on the southern WFS) during 1995 and early 1996 show a single LC impact, beginning in early July and terminating in mid-August 1995 (Fig. 3b). Both TS61 and the co-located altimetry show a 50–70 cm/s northward circulation at TS61 during and following this southern impact (Fig. 3b), with a southward flow at TS51 and very weak flow at TS41. Moreover, the instruments on the 31 and 47 m isobaths record mostly northward flow at this time. The trans-shelf southward circulation predicted by Hetland et al. [1999, 2001], is not observed. Other counter-flowing states are observed but altimetry does not indicate a concurrent LC impact on the southern shelf. The limited observations considered here are not able to of thoroughly test the theory of *Hetland et al.* [1999, 2001].

In summary, year-long in-situ velocity measurements across the shelf break and outer shelf regions of the WFS show complex spatial and temporal structures. Over the course of one year three southward-flowing currents of LC origin were recorded. Each was short lived and none of these

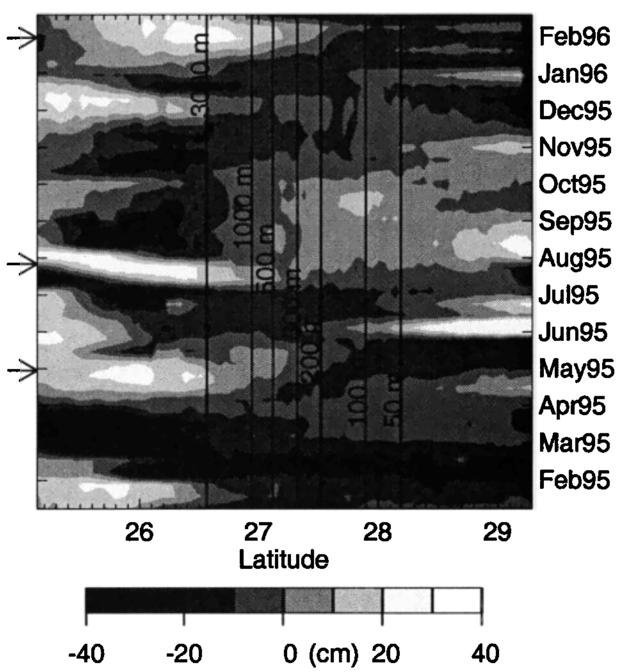

Figure 4. Sea level anomalies along TP track 91 as indicated by the scale in cm. Values greater than the limits of the contour intervals are truncated. The vertical lines indicate the isobaths underlying the TP track. Arrows indicate the LC impacts discussed in the text.

penetrated shoreward beyond about the mid-shelf ($\lesssim$100 m depth). Even at the 300 m isobath there were long durations of nominally small flow and a nearly equal likelihood for the flow direction to be either southward or northward. Understanding the nature of the WFS coupling with the deep Gulf of Mexico and LC remains an important goal and will require coordinated observation and model studies.

Acknowledgments. This work was supported by a cooperative agreement with the United States Geological Survey (Center for Coastal Geology, St. Petersburg, FL), by the Office of Naval Research grant #N00014-98-1-0158, and the Minerals Management Service, cooperative agreement #14-35-0001-30787. We thank G. Mitchum for access to the altimetric data supported by NASA as part of the TOPEX Altimeter Research in Ocean Circulation Mission, and R. Hetland for helpful discussions.

References

Cragg, J., G. T. Mitchum, and W. Sturges, Wind-induced sea-surface slopes on the West Florida Shelf, *J. Phys. Oceanogr.*, *13*, 2201–2212, 1993.

Hetland, R. D., Y. Hsueh, R. R. Leben, and P. P. Niiler, A Loop Current-induced jet along the edge of the West Florida Shelf, *Geophy. Res. Lett.*, *26*, 2239–2242, 1999.

Hetland, R. D. and Y. Hsueh, On the decay of a baroclinic jet flowing along a continental slope, *Geophy. Res. Lett.*, submitted, 2001.

Molinari, R. L., and D. A. Mayer, Current meter observations in the continental slope at two sites in the eastern Gulf of Mexico, *J. Phys. Oceanogr.*, *12*, 1480–1492, 1982.

Niiler, P. P., Observations of low-frequency currents on the West Florida Shelf, *Memoires Societe Royale des Sciences de Liege*, *10*, 331–358, 1976.

Paluszkiewicz, T., L. P. Atkinson, E. S. Posmentier, and C. R. McClain, Observations of a Loop Current eddy intrusion onto the West Florida Shelf, *J. Geophys. Res.*, *88*, 9639–9651, 1983.

Siegel, E. M., Currents observed across the West Florida Continental Shelf, Master's thesis, University of South Florida, 1999.

Sturges, W. and R. Leben , Frequency of Ring Separations from the Loop Current in the Gulf of Mexico: A revised estimate, *J. Phys. Oceanogr.*, *30*, 1814–1819, 2000.

Weisberg, R. H., E. M. Siegel, B. D. Black, J. C. Donovan, and R. D. Cole, The West-Central Florida Shelf Circulation Project: a report on data collected using a trans-shelf array of acoustic Doppler current profilers January 1995–February 1996, technical report, College of Marine Sciences, University of South Florida, 1997.

Weisberg, R. H., B. Black, and Z. Li, An upwelling case study on Florida's west coast, *J. Geophys. Res.*, **105**, 11,459–11,469, 2000.

S. Meyers, College of Marine Science, University of South Florida, St. Petersburg, FL, 33701-5001. e-mail: smeyers@marine.usf.edu

E. Siegel, Washington Department of Ecology, Environmental Assessing Program, 300 Desmond Dr., POB 47710, Olympia, WA 98504-7710. e-mail: esie461@ecy.wa.gov

R. Weisberg, College of Marine Science, University of South Florida, St. Petersburg, FL, 33701-5001. e-mail: rweisberg@marine.usf.edu

(Received August 23, 2000; revised February 21, 2001; accepted February 28, 2001.)